Quantifying an Uncertain Future: Hydrologic Model Performance for a Series of Realized "Future" Conditions

Darius J. Semmens[1], Mariano Hernandez[2], David C. Goodrich[2], and William G. Kepner[1]

[1]**U.S. EPA/Office of Research and Development (ORD)**/National Exposure Research Laboratory (NERL)/ Environmental Sciences Division (ESD); [2]**U.S. Department of Agriculture (USDA)**/ Agricultural Research Service (ARS)/Southwest Watershed Research Center

Abstract:

A systematic analysis of model performance during simulations based on observed land-cover/use change is used to quantify errors associated with simulations of known "future" conditions. Calibrated and uncalibrated assessments of relative change over different lengths of time are also presented to determine the types of information that can reliably be used in planning efforts for which calibration to future conditions is not possible. Analyses are carried out for the Soil & Water Assessment Tool (SWAT) hydrologic model in the San Pedro River Basin where four classified land-cover/use maps were developed during the period of 1973-1997.

Introduction:

- Alternative futures analyses are an important component of regional land-use planning efforts that consider a range of choices and outcomes
- Projected future land-use/cover maps developed during the planning process can be used to derive inputs for hydrologic response models
- Need to establish the validity of hydrologic-change assessments associated with alternative futures analyses to promote their use in planning efforts for informed, proactive management decisions

Research Objectives:

- Use observed changes as a proxy for future conditions to evaluate model performance for different types of applications if future conditions are known
- Evaluate model predictions of water yield for initially calibrated and uncalibrated simulations using observed and historic rainfall
- Evaluate distributed predictions of water-yield change relative to baseline conditions for initially calibrated and uncalibrated simulations using observed and historic rainfall
- Identify conclusions that can be drawn from different levels of analysis

Methods:

Study Area

- Upper San Pedro River Basin in northern Sonora, Mexico, and southeastern Arizona (Figure 1)
- Significant increases in urbanized area, irrigated agriculture, and mesquite woodland during the 24-year period of this analysis (Figure 2)

Model

- Used the Automated Geospatial Watershed Assessment (AGWA) GIS-based hydrologic modeling tool to derive inputs for the Soil & Water Assessment Tool (SWAT) distributed hydrologic model
  - Model inputs derived from observed land-cover/use maps from 1973, 1986, 1992, and 1997, together with climatic (temperature and distributed precipitation) and flow observations (Figure 3)
  - Calibrated to baseline conditions (1973 land cover, 1966-1975 climate) for average annual water yield

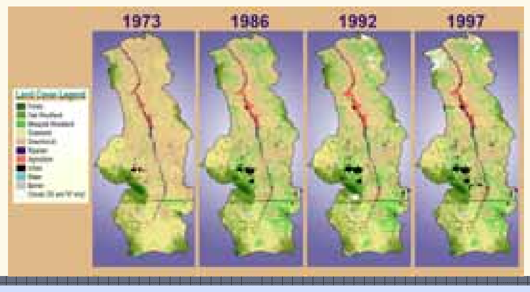
Simulations

- Ran simulations based on the 1986, 1993, and 1997 land-cover maps for the equal-length periods of 1979-1988, 1985-1994, and 1900-1999, respectively
- Four sets of simulations
  - Initial calibration with subsequent modifications to parameters derived from land cover and incorporation of known changes in management – common components of alternative future analyses
  - Uncalibrated with changes in land cover and management
  - Observed climate for each simulation period
  - Climate for each simulation derived from baseline period 1966-1975

Analysis

- Evaluated model performance for each simulation period
- Using AGWA, simulation results were compared to derive predicted change between the baseline conditions and three "future" scenarios for each of the four simulation methods

Figure 2. Observed land-cover change in the San Pedro Basin, 1973-1997.



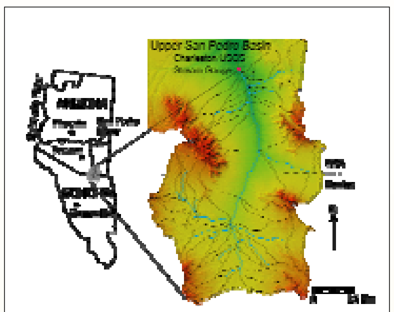


Figure 1. Map showing the location of the Upper San Pedro River Basin and the watershed discretization for SWAT, with 53 subwatersheds.

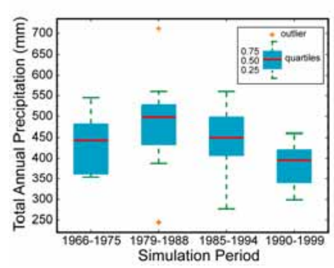


Figure 3. Box plot showing the spread and distribution of total annual precipitation for each simulation period.

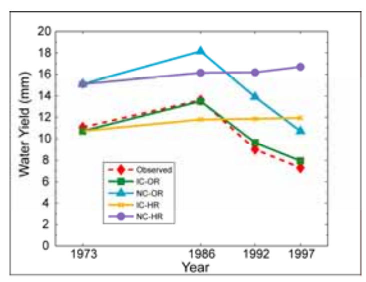


Figure 4. Observed and simulated average annual water yield (mm). Simulations are abbreviated as: initial calibration (IC), no calibration (NC), observed rainfall (OR), and historic rainfall (HR).

Table 1. Nash Sutcliffe model efficiencies for the simulation periods around each land-cover dataset.

Simulation	1973	1986	1992	1997
Initially calibrated, observed climate	0.89	0.72	0.94	0.5
No calibration, observed climate	0.04	0.25	-1.21	-1.4
Initially calibrated, '66-'75 climate	0.89	0.21	-1.2	-4.69
No calibration, '66-'75 climate	0.04	0.12	-4.65	-13.9

Results – Model Performance:

- Initially calibrated simulations based on observed rainfall (IC-OR) produce the best results, as expected (Figure 4 and Table 1)
- Uncalibrated simulations based on observed rainfall (NC-OR) consistently over-predict average annual water yield
- Initially calibrated simulations based on historic rainfall (IC-HR) produce results that are of the correct magnitude, but cannot account for changing climate
- Uncalibrated simulations based on historic rainfall (NC-HR) were the least successful at predicting water yield

Results – Forecasted Change:

- Climate is dominant factor governing water-yield change
- Major spatial patterns of predicted change are quite similar despite the fact that different, distributed rainfall inputs were used (Figure 5)
  - Subwatersheds exhibiting the greatest changes (positive and negative) match reasonably well between all four sets of simulations
  - Areas of maximum water-yield change correspond with those characterized by sufficient land-cover/use change to dominate hydrologic response over climate
- Simulations based on historic rainfall better illustrate where changes occur relative to baseline conditions because strong climatic influence is removed

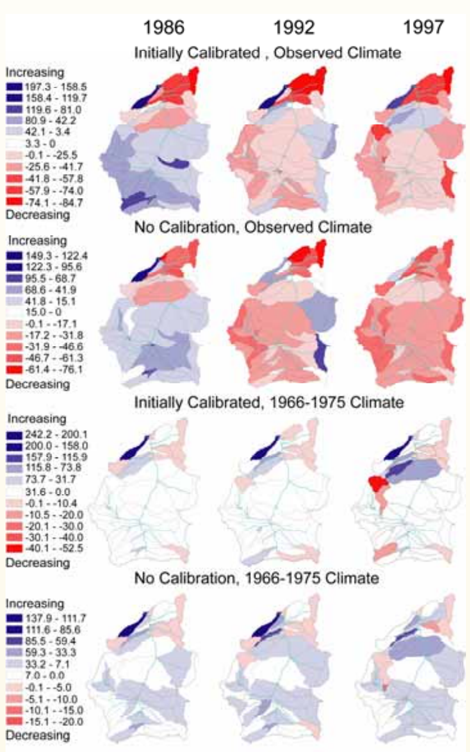


Figure 5. Maps showing change in average annual water yield relative to the 1973 baseline conditions.

Conclusions:

Decreasing cost of application

- Quantitative predictions of future hydrologic response only possible with a calibrated model AND when future climate is exactly known
- Running future simulations for dry, average, and wet periods with a calibrated model would permit quantitative water yield and water-yield change assessments with error bars to accommodate climatic uncertainty
  - Expert users derive reliable, quantitative results with uncertainty
  - High cost of application and only possible where sufficient data are available
- General, qualitative predictions of future hydrologic response (water-yield change) possible without a calibrated model
  - Permits use of AGWA by non-experts to rapidly and inexpensively compare and contrast multiple future scenarios in terms of their hydrologic impacts
  - Sufficient data are available to permit this application anywhere in the U.S.

USDA ARS US Department of Agriculture Agricultural Research Service

Southwest Watershed Research Center Tucson, Arizona

AGWA

United States Environmental Protection Agency

epascienceforum 2006 Your Health • Your Environment • Your Future

113LEB06 SF SEMMENS